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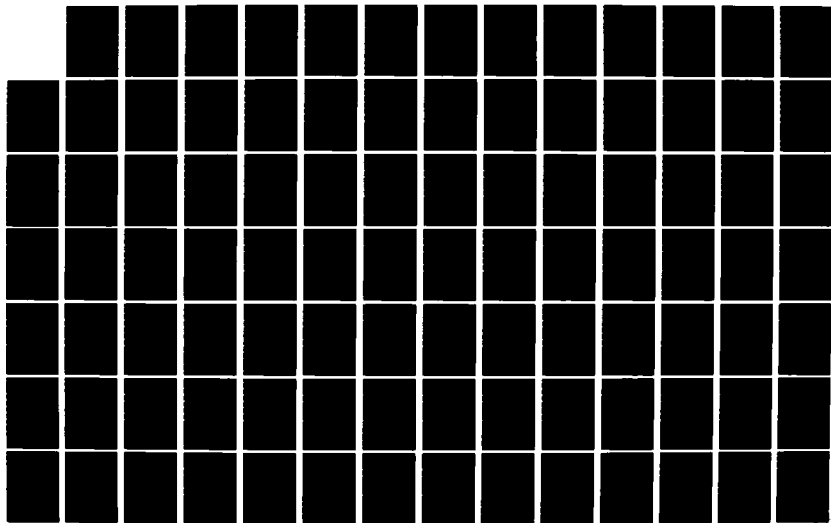
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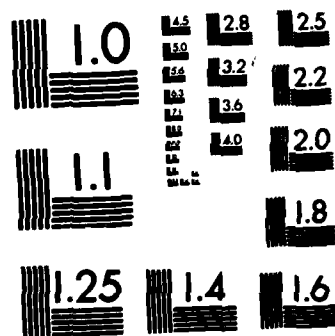
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A REVIEW OF THE CURRENT STATE OF EUROPEAN RESEARCH  
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FINAL SCIENTIFIC REPORT TO CONTRACT AFOSR-81-0065

A REVIEW OF THE CURRENT STATE OF EUROPEAN RESEARCH AND KNOWLEDGE  
CONCERNING THE BIOLOGICAL EFFECTS OF RADIOWAVES AND MICROWAVES

by

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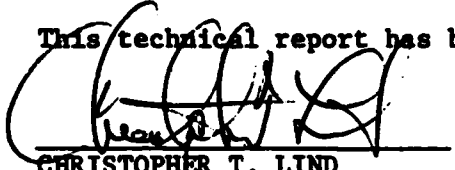
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This report has been reviewed by the EOARD Information Office and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.



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Lt Colonel, USAF  
Chief, Biotechnology

FOR THE COMMANDER



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Deputy Commander

## TABLE OF CONTENTS

1. Introduction
2. European and other microwave and radiofrequency exposure standards
3. Research in Belgium
4. Research in France
5. Research in Federal Republic of Germany
6. Research in Italy
7. Research in Ireland (Republic of Ireland)
8. Research in Scandinavia
9. Research in United Kingdom

## Introduction

Both Professor Grant and I were pleased to be approached by Major C.T. Lind on behalf of Mr. J. Mitchell of USAF School of Medicine, Brooks Air Force Base, Texas, U.S. with a request that we prepare a scientific report on work being performed in Europe concerning the biological effects of radiowaves and microwaves. It was also asked that the latest information on radiowave and microwave exposure standards should be included in the report so we approached Mr. Frank Harlen of NRPB with a request that he should contribute to the project.

The original plan was that EHG should act as editor and project co-ordinator with Frank Harlen and me assisting. For reasons, not totally unconnected with the reorganisation taking place within London University at present Professor Grant felt unable to shoulder the major responsibility for producing this document and I agreed to take over as "prime mover"; I would however like to acknowledge the contributions made by both E.H. Grant and F. Harlen.

Regarding European research, my approach was to contact as many laboratories as possible. In all cases as well as requesting details of the work being performed I asked for names and addresses of other workers within the country concerned and then followed up any additional contacts.

We also visited some laboratories in order to observe and discuss the work at first hand. I have not named those laboratories visited since this might reflect unfairly on the others in a way that was certainly not intended; indeed had time permitted we would like to have visited every laboratory mentioned.

However in view of the vast size of Europe it is possible that some important work may have been omitted. I would like, at this stage, to apologise to anyone who has been overlooked and to assure them that no slight upon their work was intended.

Since both microwave research and indeed safety standards are continually developing and evolving I hope that this may not be a definitive report and that amendments and even a new report may be requested in the future. In anticipation that I may be involved in some way in any future work I should be very pleased to receive details of any new work or to hear from anyone who has been omitted from the present document. Indeed should this report do no more than provide a useful list of names and addresses and give a stimulus for further work then I feel that a useful purpose will have been served.

Finally I wish to thank all the many people who have been good enough to take time to write to me and I hope that they will feel that I have done justice to their work.

RJS London 1982

**EUROPEAN AND OTHER MICROWAVE AND RADIOFREQUENCY  
EXPOSURE STANDARDS**

## 2.1 INTRODUCTION

Despite the considerable scientific and public interest in the subject of MW and RF exposures - MW in this document meaning RF of frequency greater than 300 MHz - most nations appear not to provide any formal governmental guidance on exposure limits. About 5 years ago the Regional Offices of WHO distributed copies of a questionnaire to all countries with whom WHO had contacts asking for information about national exposure standards applying to non-ionising radiations. This enquiry was initiated by the European Office and their files indicate that only 35 countries seem to have responded, with 23 of these stating that they did not have civilian occupational or public health MW or RF exposure limits. These included 7 NATO countries whose armed forces presumably operated within the limits of the Standardisation Agreement for Control and Recording of Personnel Exposure. It is believed that Warsaw Pact countries also work to a common standard but no details are available. Yugoslavia has controlled military exposures since 1969 but has no regulations applying to civil workers or members of the public. When the questionnaire was replied to there were no protection standards in Finland but these have been developed subsequently. Similarly, 1 state in Australia now has a  $10\text{mW/cm}^2$  limit specifically for 915 and 2450 MHz, said to have been instituted with MW oven service engineers in mind. India and Israel both stated that they worked to ANSI C95.1 (1966).

Of the remaining 12 countries it is unclear from the WHO files available for consultation whether Belgium also worked to ANSI C95.1 or had legislation based on this - the files have little detailed information. Unless there has been a change in the last year or so, French legislation applies only to civilian employees at military establishments. The exposure limit is  $10\text{mW/cm}^2$  for frequencies greater than 10 MHz. China appears not to have responded to the original questionnaire but for 2 years has now been operating experimentally, and in 1 province only, a  $300\mu\text{W/cm}^2$  standard for exposure durations of up to 6 hours. The only other countries known to have made civil regulations or codes of practice on exposure limits are: Bulgaria, Canada, Czechoslovakia, German Democratic Republic, German Federal Republic, Poland, Sweden, UK, USA and USSR. With Finland

and China this makes for a total of 12 existing national civil standards and 2 military standards (NATO and Yugoslavia) which can be compared and discussed.

The USA and the USSR were the first countries to promulgate standards for control of occupational exposure to MW radiation, and both countries made only minor changes in their limits in the intervening 25 to 30 years. For long exposures these differed originally by a factor of 1000, reduced to 400 since 1/1/82 when the 8 hour USSR limit was raised from 10 to  $25\mu\text{W}/\text{cm}^2$  and 200 to 40 with the revision of the ANSI C.95 standard and its frequency dependent limits. Other countries, in making their own standards, adopted or slightly adapted those of the USA or USSR. Some of these - Canada and Sweden, Czechoslovakia and Poland - have subsequently revised their limits to be, as appropriate, rather more restrictive than those of the USA or more relaxed than those of the USSR. The standards of Finland, China and Yugoslavia may also be regarded as occupying the middle ground between the extremes originally displayed by the standards of the USA and USSR. In the German Federal Republic where the Navigators' Institute had operated a  $10\text{mW}/\text{cm}^2$  exposure limit a DIN standard was proposed in 1976. This would have reduced the whole day exposure limit from  $10\text{mW}/\text{cm}^2$  to  $1\text{mW}/\text{cm}^2$  with  $10\text{mW}/\text{cm}^2$  still permitted for only 1 hour. This provision was not included in the 1978 published version of VDE 0871/1978.

The various exposure standards may differ considerably not only in their 8 hour limits, but also in how they treat shorter exposures, the frequency limits and whether they are invariant with frequency. Current European standards are either frequency invariant in the MW region or employ step-functions between frequency regimes, while variations of exposure duration may be dealt with using either step-functions or ramps to allow exposure to higher field strengths for shorter periods. There are, in addition, various proposals for revised and new national standards which incorporate frequency dependence using ramp functions, but the recent IRPA proposal for an international standard has reverted to the use of step-functions for frequency dependence while maintaining ramps for time dependence.

Whereas there is reasonable consensus about what exposures should be accepted as permissible in the ionising and optical regimes of the electro-magnetic spectrum, the radiofrequency regime presents a complex and confusing scene. To some extent this has come about in the ways that experiments using laboratory animals have been interpreted as applying to man. For MW or RF exposures to produce any biological effect requires the absorption of energy, and developments over the last few years have promoted much greater understanding of how much energy is absorbed and where in the body, whether man or laboratory animals. At the same time there is a more numerate appreciation of the importance of body dimensions as compared with the wavelength of the MW or RF fields, and the importance of polarization of these fields. The mathematical and physical models are crude as compared with biological reality, but no more so than our understanding of many of the claimed biological effects or of their significance. Another factor has been in the philosophical approach underlying the process of generating an exposure standard. The extremes are occupational exposure levels set so low that there should be no demonstrable effects, and acceptance of some stress which is within the limits of normal compensation for most people but which may adversely affect a minority. Even when a scientific consensus has been established it may be inexpedient, socially or politically, for a nation to adopt a substantially more relaxed exposure standard than hitherto. It is also, for instance, doubtful whether there would be ready public acceptance of a  $20\text{mW}/\text{cm}^2$  in the USA or the UK at frequencies above 2 or 3 GHz (which the authors believe to be safe), no matter how convincing the scientific reasoning. Furthermore, there is no need for a more relaxed standard so the savings in monetary terms would be modest. At the same time there could be substantial opposition to the imposition of what are regarded as unnecessarily restrictive limits if these are likely to result in substantial cost or inconvenience. Sweden will almost certainly reduce their RF limit to  $1\text{mW}/\text{cm}^2$  but will leave the MW limit at  $1\text{mW}/\text{cm}^2$  which has been operated successfully.

The rationales underlying the various standards have not generally been explained in any detail by the authorities making them but it is

becoming increasingly common to provide reasons. With some older standards the scientists involved have explained some of the limits where no formal rationale has been advanced. Where available to the authors these will be summarised in the discussion of standards which follows.

## 2.2 'NORTH AMERICAN' AND 'WESTERN' EUROPEAN 10mW/cm<sup>2</sup> EXPOSURE STANDARDS

These are avowedly thermally based standards which have their origin in Schwan's advice to the US Navy in 1953. If 10mW/cm<sup>2</sup> is incident over the projected cross-sectional area of man of 0.7 m<sup>2</sup>, and is absorbed without reflections or scatter, the resulting thermal load is 70W. This is less than the resting metabolic rate of about 100W and very much less than the metabolic rate when even moderate physical effort is involved, eg. 300W when walking at 5km/h. Any thermal stress from whole body exposure to 10mW/cm<sup>2</sup> will be well within the limits of normal physiological compensation. Exposures of 10mW/cm<sup>2</sup> are also much lower than those required to cause acute injury to the eyes or testes of experimental animals and it was argued that the safety factor for demonstrable injury of these organs in man would be about 10. The insights and understanding achieved subsequently, especially during the last decade, confirm Schwan's advice for the microwave region which was his remit. US industry, as represented by the General Electric Corporation and the Bell Telephone Laboratories would have preferred a larger safety factor of between 10 and 100 so that exposures to 1 to 10mW/cm<sup>2</sup> were to be considered safe only for incidental, occasional or casual exposure. The Bell approach<sup>(1)</sup> was described in Health Physics in 1961, the year after the UK adopted the 10mW/cm<sup>2</sup> limit for the frequency range 30MHz to 30GHz. This occurred in 1960 with the publication by HM Stationery Office of the booklet: 'Safety precautions relating to intense radio-frequency radiation'. The 10mW/cm<sup>2</sup> limit prevailed also with the US military and other NATO forces. It was adopted as a civil standard by ANSI and ACGIH in the USA, by the Federal Republic of Germany, by Sweden until 1976 and by Canada until 1979. A 10mW/cm<sup>2</sup> exposure limit for the frequency range 300MHz/cm<sup>2</sup> to 300GHz is the main

feature of a draft Directive issued by the Commission of the European Community. If this CEG proposal is ratified it would be mandatory for member states to make equivalent or possibly safer regulations within a set period of time.

The various  $10\text{mW}/\text{cm}^2$  standards have differed not only in the frequency range over which they operate but also in the formulae by which higher exposures are permissible for short exposure durations. The US military, and NATO forces generally, allowed progressively higher exposures for durations of 1 hour or less through to about 2 minutes according to a formula most simply expressed in SI units:

$$T = 10^4/s^2$$

where T is expressed in hours and the power density is in watts per square metre. The limitation to 2 minutes minimum has been explained as being imposed because of the difficulty of controlling and assessing very short exposures. This is a valid consideration when personnel go into a spatially varying radiation field, but is less appropriate if the intermittent nature of the exposure comes about as a consequence of periodic pre-determined changes in the output of the equipment or of beam direction. There does not appear to have been any formal justification for the choice of the break-point of 1 hour or the square law relationship between time and exposure limit. It has, however, been conjectured that the latter may be from analogy with toxicological studies where effect can be proportional to the square of the dose. The Polish standard incorporates a square law dependence of permissible exposure and exposure duration but this extends over the whole working day. There has also been a proposed Italian standard, now abandoned as being too complex to be workable in practice, which included square law dependence over the whole working day.

The NATO forces in their latest revision - STANAG 2345 (1979) - have abandoned square law dependence in favour of the simpler approach of ANSI C95.1 (1966) which allows  $10\text{mWh}/\text{cm}^2$  in any period of 0.1 h. This formula of allowing averaging over 0.1h was adopted in the UK in 1971, has been retained by Sweden and Canada in their revised standards, and is

included in the IRPA proposals for an international standard. However, Sweden, Canada, IRPA and, at one time, ACGIH have incorporated an arbitrary  $25\text{mW/cm}^2$  ceiling limit. It is difficult to understand why this should have been judged desirable. No justification has been formally given for the 0.1h period but members of the ANSI committee which agreed this relaxation originally have variously ascribed it to consideration of the eyes and of the testes. Theoretical studies by the NRPB in the UK have validated this equilibrium time for the human eye.

In the UK the Royal Navy and RAF are working to a 1000 V/m limit for (near field) exposures between 1MHz and 30MHz and 2000 V/m for exposures below 1 MHz - the UK standard gives no numerate advice on exposures below 30MHz. The civil organisations of British Telecom and the BBC have also elected to work to 1000 V/m below 30MHz for occasional exposures. STANAG 2345 allows  $10\text{mW/cm}^2$  (200 V/m E field and 0.5 A/m H field) in the frequency range 10MHz to 300GHz,  $66\text{mW/cm}^2$  (500 V/m and 1.3 A/m) for 1MHz to 10MHz, and  $165\text{mW/cm}^2$  (1000 V/m and 2.6 A/m) for 10kHz to 1MHz. The step-functions cannot be justified biologically but they can be administratively and operationally more convenient than ramp functions. Similarly there is a little justification for equating and regarding the E and H fields as being of equivalent biological importance for frequencies below 30MHz. A new feature in this standard is the limitation of pulses to  $10^5$  V/m, equivalent to  $2.5 \times 10^3\text{W/cm}^2$ . The only other standard known to incorporate a restriction on pulse power is that of Czechoslovakia with  $10^3\text{W/cm}^2$ .

### 2.3 SOVIET AND EASTERN STANDARDS

In general, the USSR subscribes to the principle that all protection standards should be set at levels such that there is no change in the state of health or well-being as a result of such exposure. This is often much more restrictive than the 'TLV' approach favoured in the USA and many other countries, which allow the possibility of small reversible changes within the range of normal compensation of 'normal' individuals. The most recent amendments to the Soviet GOST standard 12.1.006-70 came into effect on

1.1.1982. These affect only the MW part of the standard:

- 1) The ceiling value of  $10\text{W/m}^2$  ( $1\text{mW/cm}^2$ ) for normal conditions is reduced to  $1\text{W/m}^2$  ( $100\mu\text{W/cm}^2$ ) if the temperature is higher than  $28^\circ\text{C}$ .
- 2) The maximum energy density for whole day exposure to stationary radiation is increased from  $0.8\text{Wh/m}^2$  ( $10\mu\text{W/cm}^2$  for 8h) to  $2\text{Wh/m}^2$  ( $25\mu\text{W/cm}^2$  for 8h).
- 3) The maximum energy density for non-stationary radiation is increased to  $20\text{Wh/m}^2$

Item 1) is intriguing and unexpected. The obvious interpretation is that the Soviet standards committee believe that  $1\text{mW/cm}^2$  is thermally stressing even in the MW region; we are unaware of any scientific basis for this. Military units do not have to comply with the GOST standards. The previous ANSI standard does include the suggestion that the  $10\text{mW/cm}^2$  limit should be lowered if there is thermal stress from the environment, but this is an avowedly thermal standard. The paper by Tell and Harlen<sup>(2)</sup> indicates that environmental conditions would have to be very severe before the additional thermal load from exposure to even  $10\text{mW/cm}^2$  could be a significant factor in promoting thermal stress. The SAM Dosimetry Handbooks show a maximum power absorption in the MW region of only 3W for a 70kg man for a  $1\text{mW/cm}^2$  exposure and 30W for a  $10\text{mW/cm}^2$  exposure as compared with the resting metabolic rate of 100W or more.

The relaxations of items 2) and 3) were expected and tend to produce a more even total exposure for the 3 time durations of the Soviet GOST standard. The maximum permissible MW occupational exposure levels previously allowed were  $1\text{mW/cm}^2$  for up to 20 minutes provided that  $10\mu\text{W/cm}^2$  is not exceeded at any other time during the day -  $400\mu\text{Wh/cm}^2$ ,  $100\mu\text{W/cm}^2$  for 2 hours -  $260\mu\text{Wh/cm}^2$ , and  $10\mu\text{W/cm}^2$  for 8 hours -  $80\mu\text{Wh/cm}^2$ . The revision allows  $200\mu\text{Wh/cm}^2$  over an 8 hour period. The MW limits have been explained by Soviet scientists as arising from consideration of both animal experiments and clinical symptoms developed by workers. Gordon<sup>(3)</sup> has stated that 'exposure of workers to levels between a few 10's of  $\mu\text{W/cm}^2$  and a few 100's of  $\mu\text{W/cm}^2$  usually leads to functional disturbances in the nervous system with a predominantly asthenic condition'. She is also quoted by Barenski

and Czerski<sup>(4)</sup> as saying that standards should be set a safety factor of 10 below the threshold exposure causing any clinical symptoms. Discussing animal experiments, she gives the criterion of harmfulness as functional disturbances requiring compensation which could assume a pathological character but specifically excluding reactions within normal physiological limits. The symptoms of the 'asthenic condition' include weakness, depression, impairment of memory and an inability to make decisions etc. These symptoms are non-specific to MW or even RF radiation, generally. They have been reported, for instance, in the USA in residents of Three Mile Island. Gordon does not discuss what control population she used. Petrov and Subbota<sup>(5)</sup> state that the threshold for functional disturbances in animals for 1 hour exposures at 3GHz is  $1\text{mW}/\text{cm}^2$ . Taking this to be equivalent to  $100\mu\text{W}/\text{cm}^2$  for 10 hours (a working day) and applying a safety factor of 10 to allow for individual variations in susceptibility results in  $10\mu\text{W}/\text{cm}^2$ .

For frequencies below 300MHz the permissible Soviet occupational exposure limits are expressed in terms of the electric and/or magnetic field strengths and the author is not aware of any relaxation for exposure durations shorter than the whole working day. Between 50 and 300MHz the limit is 5 V/m, between 30 and 50MHz the limits are 10 V/m and 0.3 A/m. From 3MHz to 30MHz the limit is 20 V/m, and is 50 V/m from 60kHz to 3MHz. From 60kHz to 1.5MHz 5 A/m is allowed. The new MW occupational limit of  $25\mu\text{W}/\text{cm}^2$  for all day exposure to RF above 300MHz is equivalent to about 10 V/m and 0.025 A/m for radiated power. The  $100\text{mW}/\text{cm}^2$  limit of the proposed ANSI and ACGIH standards for exposures at frequencies below 3MHz also expressed as 630 V/m and 1.6 A/m. The Soviet standard below 1.5 MHz is, therefore, much more restrictive in respect of the electric field and is more relaxed about the magnetic field in this frequency regime than the ANSI (1982) or the ACGIH proposed standards. The author has no knowledge of any explanations having been advanced for the Soviet limits. Electric fields will generally deposit more energy in man than the equivalent magnetic fields but not to the extent implied in the Soviet limits.

Czechoslovakia originally used Soviet limits but established its own independent standard in 1965 - Regulation HE-344, the first of the

Eastern European countries to do so. For occupational exposures of up to 8 hours  $25\mu\text{W}/\text{cm}^2$  CW and  $10\mu\text{W}/\text{cm}^2$  pulsed were accepted as 'safe', the permitted exposure of the general population being a factor of 10 lower. The peak power density may not exceed  $10^3\text{W}/\text{cm}^2$  which is surprisingly close to the NATO limit. For exposures shorter than the whole working day there is a reciprocity between exposure and exposure duration, as with the much shorter Western 0.1h averaging. Apparently, averaging may be carried out over a period as long as 1 working week - this information being obtained in a personal communication from K. Marha who was prominent in this field in Czechoslovakia and is now resident in Canada. However, the Czechoslovak limits are so close to those of the USSR and low that for a 0.1h exposure averaged over a 5 day week only  $10\text{mW}/\text{cm}^2$  would be allowed. These limits apply over the frequency range 300MHz to 300GHz. A modification to Regulation HE-344 was published in 1965 which allows exposure to 10 V/m over the frequency range 30MHz to 300MHz and 50 V/m over the range 30kHz to 30MHz. These are for 8 hour exposures with reciprocity for shorter durations, presumably as time and the square of electric field strength.

There appear to be no civil exposure standards in Yugoslavia but in a personal communication Prof.Dr. Zoran Djordevic, of the Yugoslavian Institute of Aviation Medicine, summarised the airforce regulations which date from 1969:

- 1) Zone of very intensive MWR: which covers the area of power density greater than  $10\text{mW}/\text{cm}^2$ . Personnel without protective suits are not allowed to enter this zone.
- 2) Zone of intensive MWR: which covers the area of power density from 1 to  $10\text{mW}/\text{cm}^2$ . Personnel are forbidden to stay longer than 15 minutes within a 24 hour period.
- 3) Zone of moderate MWR: which covers the area of power density from 0.1 to  $1\text{mW}/\text{cm}^2$ . Personnel are forbidden to stay longer than 3 hours within a 24 hour period.
- 4) Zone of weak MWR: which covers the area of power density lower than  $0.1\text{mW}/\text{cm}^2$ . Personnel are allowed to stay in this area for an unlimited period of time.

This is, therefore, with Poland the most relaxed of the known Eastern

European standards but the authors are unfamiliar with other Eastern European military standards. Prof. Djordevic is somewhat caustic about the "epidemic" of microwave damages of humans 'in some countries where standards on protection against MW radiation are more strict than in Yugoslavia'. Prof. Djordevic has published a monograph 'Microwave Radiation and Protection' VIZ Beograd 1978 which he says gives the detailed presentation and comments on the Yugoslavian regulations.

Poland, as with Czechoslovakia originally adhered to the MW Soviet standards but introduced new regulations in 1972. As with Yugoslavia these use the concept of 4 zones for occupational exposure to MW radiation.

- 1) Safe zone: the mean power density cannot exceed  $10\mu\text{W}/\text{cm}^2$ : human exposure is unrestricted.
- 2) Intermediate zone: power densities between  $10\mu\text{W}/\text{cm}^2$  and  $200\mu\text{W}/\text{cm}^2$ : occupational exposure is allowed throughout the working day.
- 3) Hazardous zone: power density  $P$  in  $\text{mW}/\text{cm}^2$  between  $200\mu\text{W}/\text{cm}^2$  and  $10\text{mW}/\text{cm}^2$ : Occupational exposure in any period of 24h is determined by the formula

$$T \text{ (hours)} = 3.2/P^2$$

- 4) Dangerous zone: power densities exceeding  $10\text{mW}/\text{cm}^2$ : human exposure is forbidden.

Higher levels up to  $10\text{mW}/\text{cm}^2$  were permitted for non-stationary beams. The square law relationship between power density and exposure duration is similar to that adopted by the US armed forces and NATO for durations of less than 1 hour. According to Barenski and Czerski<sup>(4)</sup> - epidemiological studies of workers provided the basis of the new standard. They explain that although limits and regulations were introduced into Poland in 1961 that 'as in other countries only gradual enforcement was possible'.

Subjective complaints were as described by Soviet authors<sup>(5)</sup>. New regulations introduced in 1977 extended the concept of zones to lower frequencies. For the frequency range 10 to 300MHz: 7 V/m was regarded as safe, 7 to 20 V/m was permissible in the intermediate zone and 20 to 300 V/m in the hazardous zone. For 0.1 to 10MHz: the permissible field strengths in the safe zone were 20 V/m and 2 A/m, with 20 to 70 V/m and 2 to 10 A/m in the intermediate

zone, and 70 to 1000 V/m and 10 to 250 A/m in the hazardous zone. For all day occupational exposures the electric field strengths are reasonably in line with but somewhat more relaxed than those of other Eastern European nations (Table 1). The magnetic field strengths are, however, very high and could be expected to cause unacceptable high SARs. Exposure to such high fields without concomitant exposure to fairly high electric fields seems hardly possible as an occupational risk.

In 1973 the German Democratic Republic introduced relaxations on the Soviet limits but reverted to those of the USSR in 1975. The Bulgarian standards appear to be no more than translations of Soviet documents. Finally, the People's Republic of China has been operating a trial standard in just one state since August 1978. This allows  $300\mu\text{W}/\text{cm}^2$  during a 6 hour day ie. an average of  $50\mu\text{W}/\text{cm}^2$ . This limit was reached after consideration of epidemiological studies involving 1,342 microwave workers and of animal experiments. Workers exposed to more than  $200\mu\text{W}/\text{cm}^2$  showed some slight clinical signs. Workers exposed to less than  $50\mu\text{W}/\text{cm}^2$  showed no signs or symptoms other than neuroasthenic symptoms<sup>(6)</sup>.

#### 2.4 SWEDEN, CANADA AND FINLAND

Sweden and Canada originally adopted the ANSI C95.1  $10\text{mW}/\text{cm}^2$  limit but in 1976 and 1979, respectively, made restrictive changes. Sweden changed to  $5\text{mW}/\text{cm}^2$  for the frequency range 10 to 300MHz, and to  $1\text{mW}/\text{cm}^2$  for 300MHz to 300GHz. The averaging time of 0.1h is retained and there is an instrumental (1s) ceiling of  $25\text{mW}/\text{cm}^2$ . No scientific justification has been published. It is understood that the committee were primarily concerned about possible teratological effects but the papers cited are of exposure of rats to 27MHz fields. They were perhaps unfortunate in making the change when they did, before there was wide appreciation that man as a lossy antenna is most efficient at absorbing RF power in the frequency range 30 to 300MHz. It is likely that the standard will be revised to a flat  $1\text{mW}/\text{cm}^2$  limit over the frequency range

30MHz to 300MHz.

In 1977 it seemed possible that Canada would adopt a simple  $1\text{mW}/\text{cm}^2$  over the frequency range 10MHz to 300GHz on the grounds that the  $10\text{mW}/\text{cm}^2$  standard paid too little consideration to Eastern studies. The official recommendations which followed in 1979 were explained to the author as representing a compromise but, by that time, at least the first SAM Dosimetry Handbook would have been available to the Canadian authorities. The Federal recommendations are for  $1\text{mW}/\text{cm}^2$  from 10MHz to 1GHz, and  $5\text{mW}/\text{cm}^2$  from 1GHz to 300GHz. These are for occupational exposure, public exposure is limited to  $1\text{mW}/\text{cm}^2$ . As with the Swedish standard, time averaging over 0.1h is permissible to a ceiling limit of  $25\text{mW}/\text{cm}^2$ .

Finland has been operating a  $0.1\text{mW}/\text{cm}^2$  limit for the frequency range 100MHz to 100GHz for about a year, with exposures of up to  $1\text{mW}/\text{cm}^2$  for 10 minutes in any hour. K. Jokela of the Finnish Institute of Radiation Protection believes that these limits are unnecessarily restrictive and expects Finland to make more relaxed limits within a year or so.

## 2.5 PROPOSED STANDARDS

The best known of the proposed standards, that of ACGIH (1981) is essentially US but this and ANSI C95 are likely to prove influential with the 0.4 W/kg absorption criterion being widely copied except perhaps among countries already operating a more restrictive standard. However, near and below resonance the exposure limits of the two standards tacitly assume that the fields extend to several times the dimensions of man. This is very unlikely in the situations where field strengths comparable with the limits are commonly encountered. As mentioned previously in the discussion of the NATO standard and the Soviet standard, the electric field worst case orientation will deposit more power than the 'equivalent' magnetic fields. The ANSI

justification for limiting both field strengths below 3MHz to those associated with a plane-wave-equivalent power density of  $100\text{mW}/\text{cm}^2$  is that 'this limit is intended to prevent reactions at the body's surface that can occur in E fields of high density'. No numerical examples or literature references are cited. The proposed IRPA/INIRC Guidelines appear to be an extension and simplification of the Canadian Regulations and would allow  $5\text{mW}/\text{cm}^2$  from 1GHz to 300GHz,  $1\text{mW}/\text{cm}^2$  from 10MHz to 1GHz,  $10\text{mW}/\text{cm}^2$  from 1MHz to 10MHz, and  $25\text{mW}/\text{cm}^2$  from 100kHz to 1MHz. These limits are also expressed in terms of the equivalent plane-wave electric and magnetic field strengths, and 6min (0.1h) averaging is permitted. The rationale relies heavily on that of ANSI and the 0.4W/kg criterion but for frequencies below 10MHz the members of IRPA/INIRC only adduce that an added safety margin was incorporated 'because one cannot necessarily assume that a biological effect is directly related to the amount of energy absorbed'. The use of step-functions is justified as being desirable from a compliance viewpoint. Thus IRPA/INIRC are applying additional safety factors to the safety factors and conservative approach of ANSI and ACGIH.

There is a current draft Directive from the Commission of the European Communities which is essentially thermal in its approach and would allow  $10\text{mW}/\text{cm}^2$  with 0.1h averaging over the MW region 300MHz to 300GHz. It is not unlikely that the IRPA proposal may supplement this. If a CEC Directive is confirmed then member nations of the European Community (EC) have to make equivalent regulations, though national regulations may be more restrictive if this does not restrain trade between member nations. Members of the EC known to be considering new MW and/or RF exposure standards include the German Federal Republic and Italy. Denmark is a member of the EC and also the Nordic 'Community', delegates from which met in Stockholm on 25th and 26th May 1982 to discuss non-ionising radiations generally, and whether common standards could be adopted. There were already proposals for new standards in Finland, Norway and Sweden. In Sweden, for instance, they are thinking in terms of  $1\text{mW}/\text{cm}^2$  from 30MHz to 300GHz,  $5\text{mW}/\text{cm}^2$  from 3MHz to 30MHz

and  $25\text{mW/cm}^2$  from 100kHz to 3MHz. Exposure limits for frequencies below 300MHz are expressed as magnetic and electric field strengths equivalent to the plane wave power densities. Six minute averaging is allowed and there is a 7W exclusion clause. In discussion with one of the authors of this paper Dr. Paulsson of the Swedish Institute of Radiation Protection agreed that the  $1\text{mW/cm}^2$  limit above 300MHz was being maintained because, with their present standard, this limit was being achieved. The population of Sweden is about twice that of any of their Nordic neighbours and the effort they are applying to NIR, particularly RF, is considerably higher than the population ratios. The tentative proposals from Norway and Finland are not very different and it is reasonable to expect that Swedish opinion will be the most important factor if there is a Nordic consensus standard. This will be more restrictive than the proposed IRPA/INIRC guidelines. It is a reasonable expectation that their armed forces would need to be overtly excluded with a similar provision in other EC countries if the present IRPA/INIRC proposal becomes the basis of an EC Directive. It is expected that a proposed standard for the UK will be available for comment in early 1983 and present indications are that the limits will be similar to those of ANSI (1982) and the ACGIH (1981) proposal. A Federal German Republic DIN standard is not expected for at least a year, but no details of what is likely are known to the author. However, two years ago the curves of fig. 4 were made available to members of the IEC (International Electrotechnical Commission) working group. It seems probable that the permissible power density for the frequency range 30 to 300MHz was  $25\text{ W/m}^2$  not the  $20\text{ W/m}^2$  entered on the Y axis. It is also possible that the break-point at 3000MHz was also not intended and constitutes a drafting error for 300MHz. With these 'corrections' it becomes possible to discern a possible logic underlying the proposed exposure limits.

Two other proposed standards, for Italy<sup>(7)</sup> and Australia<sup>(8)</sup> were also published in 1979 and received much wider circulation. The presentation of the Italian proposal of fig. 5 is unusual and is identical to the presentation of the Polish standard by two Polish authors<sup>(4)</sup>. The proposed Italian standard is also unusual in relating permissible

exposure duration with the square of the incident power density: the Polish standard represents the only other proposed, present or previous standard incorporating this square law relationship for the whole working day known to the authors of this document. The English abstract of ref<sup>(7)</sup> includes in its purpose a rationale for its proposed limits, but the authors of this review document have not seen any English translation of the published rationale. We have also been told that the proposal has been withdrawn as being too complex to assess exposures in the working environment. The Australian proposal<sup>(8)</sup> is presented in its essentials in fig. 6.

Table 1. Electric field strength (V/m) for 8h exposure

| Frequency range | USSR | Czechoslovakia | Poland |
|-----------------|------|----------------|--------|
| 300GHz - 30MHz  | 10   | 10             | 27     |
| 300MHz - 50MHz  | 5    |                |        |
| 300MHz - 30MHz  |      | 10             |        |
| 300MHz - 10MHz  |      |                | 20     |
| 50MHz - 30MHz   | 10   |                |        |
| 10MHz - 100kHz  |      |                | 70     |
| 30MHz - 60kHz   | 50   |                |        |
| 30MHz - 30kHz   |      | 50             |        |

Table 2. Present NATO Standard (Stanag 2345)

| Frequency<br>(MHz) | Power density<br>(W/m <sup>2</sup> ) | E<br>(V/m) | H<br>(A/m) |
|--------------------|--------------------------------------|------------|------------|
| 0.01 - 1           | 2650                                 | 1000       | 2.6        |
| 1 - 10             | 660                                  | 500        | 1.3        |
| 10 - 300,000       | 100                                  | 200        | 0.5        |

Table 3. Exposure data for Sweden (1976)

| Frequency<br>(MHz) | Power density<br>(W/m <sup>2</sup> ) |
|--------------------|--------------------------------------|
| 10 - 300           | 50                                   |
| 300 - 300,000      | 10                                   |

Note there is an averaging time of 0.1h with a ceiling limit of 250 W/m<sup>2</sup> and a 1 s instrumental averaging time is assumed.

Table 4. USSR 1970 Microwave exposure data (300MHz-300GHz)

| Power Density                               | Remarks  |
|---|--|
| 100 mW/m <sup>2</sup>                       | Exposure up to 8h  |
| 1000 mW/m <sup>2</sup> (1W/m <sup>2</sup> ) | Exposure up to 2h  |
| 10 W/m <sup>2</sup>                         | Exposure 15 to 20 min but<br>100 mW/m <sup>2</sup> must not be<br>exceeded at any other<br>time during the day |

Table 5. USSR 1978 Radio frequency exposure data  
(0.06-300MHz)

| Frequency<br>(MHz) | E<br>(V/m) | H<br>(A/m) |
|--------------------|------------|------------|
| 0.06 - 1.5         | 50         | 5          |
| 1.5 - 3            | 50         |            |
| 3 - 30             | 20         |            |
| 30 - 50            | 10         | 0.3        |
| 50 - 300           | 5          |            |

Table 6. Czechoslovakia-radiofrequency and microwave exposure data  
(1968)

| Frequency       | Exposure limit                | Exposure duration |
|-----------------|-------------------------------|-------------------|
| 30 kHz - 30 MHz | 50 V/m                        | 8 hours           |
| 30 MHz - 300MHz | 10 V/m                        | 8 hours           |
| 300MHz - 300GHz | 0.25 W/m <sup>2</sup> - CW    | 8 hours           |
|                 | 0.1 W/m <sup>2</sup> - Pulsed |                   |

Table 7. Exposure data for the German Democratic Republic (1973)

| Power density<br>$\text{W/m}^2$ | Remarks             |
|---------------------------------|---------------------|
| 1                               | Exposure for 8h day |
| 5                               | Exposure for 3h     |
| 10                              | Exposure for 20m    |

Note

The above are for CW and must be reduced by a factor of 2 for pulsed radiation.

Table 8. Exposure data (1972) for Poland (300MHz-300GHz)

| Zone         | Power density<br>(W/m <sup>2</sup> ) | Remarks   |
|--------------|--------------------------------------|---|
| Safe         | 0.1                                  | Human exposure unrestricted   |
| Intermediate | 0.1 - 2                              | Allowed for the working day   |
| Hazardous    | 2 - 100                              | Exposure is allowed in any 24h<br>according to the formula $t = \frac{32}{S^2}$ |
| Dangerous    | greater than<br>100                  | Human exposure forbidden  |

Table 9. Poland - Exposure data (1977) for 0.1MHz-300MHz

| Frequency<br>(MHz) | Zone         | E<br>(V/m) | H<br>(A/m) |
|--------------------|--------------|------------|------------|
| 0.1 - 10           | Safe         | 20         | 2          |
|                    | Intermediate | 70         | 10         |
|                    | Hazardous    | 1000       | 25         |
|                    | Dangerous    | >1000      | >250       |
| 10 - 300           | Safe         | 7          |            |
|                    | Intermediate | 20         |            |
|                    | Hazardous    | 300        |            |
|                    | Dangerous    | 300        |            |

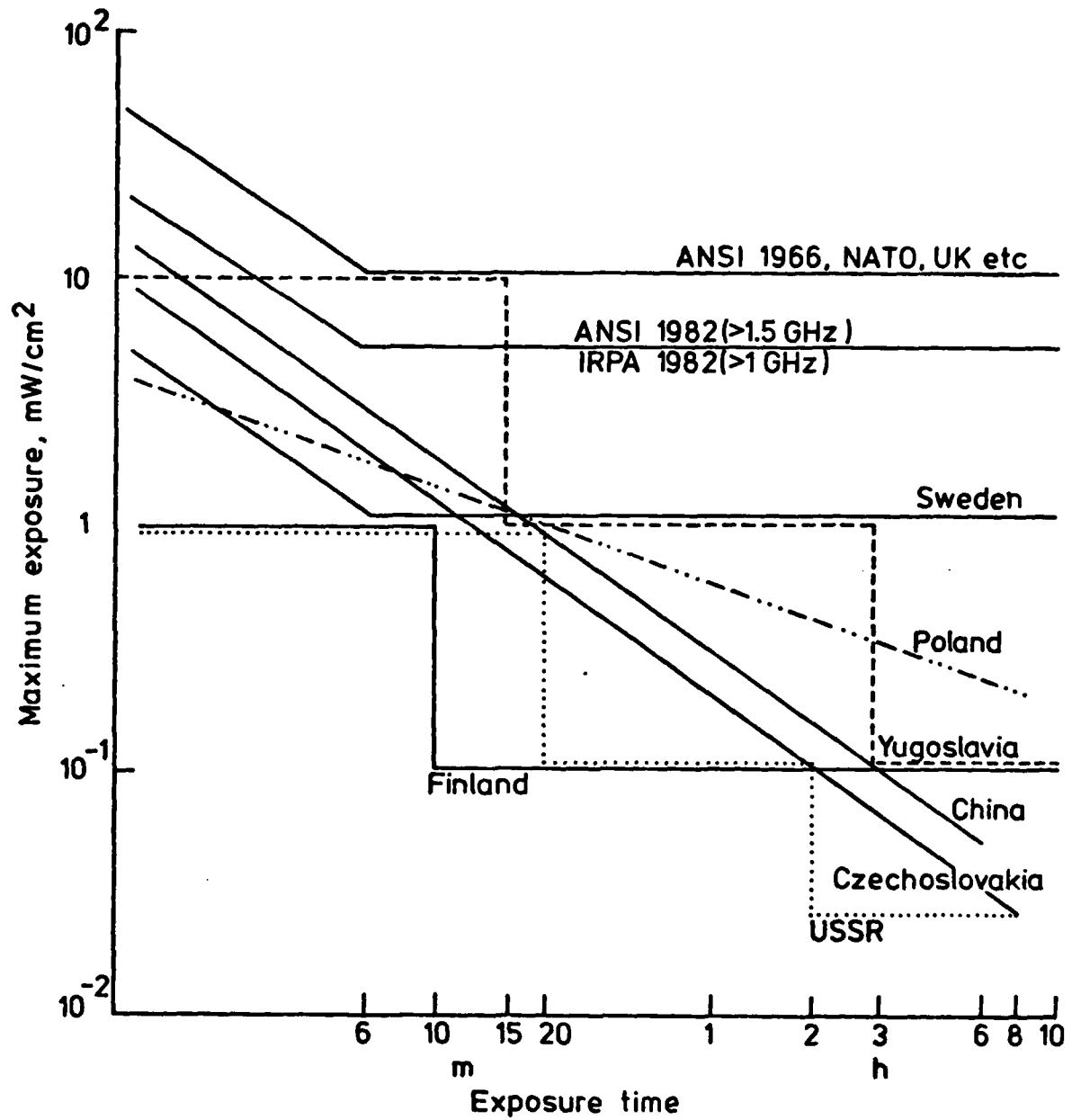


Figure 1 Some microwave exposure standards

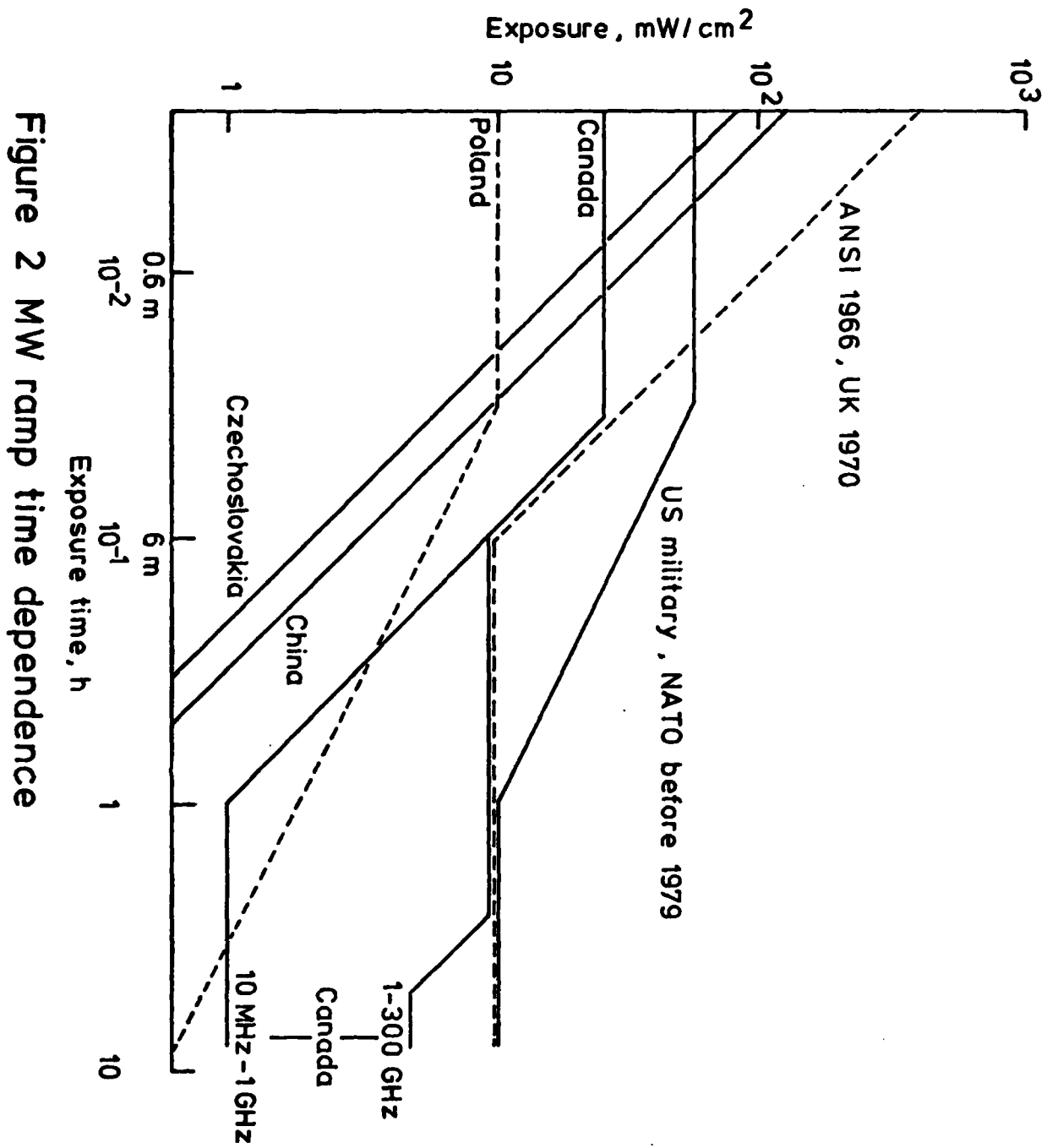


Figure 2 MW ramp time dependence

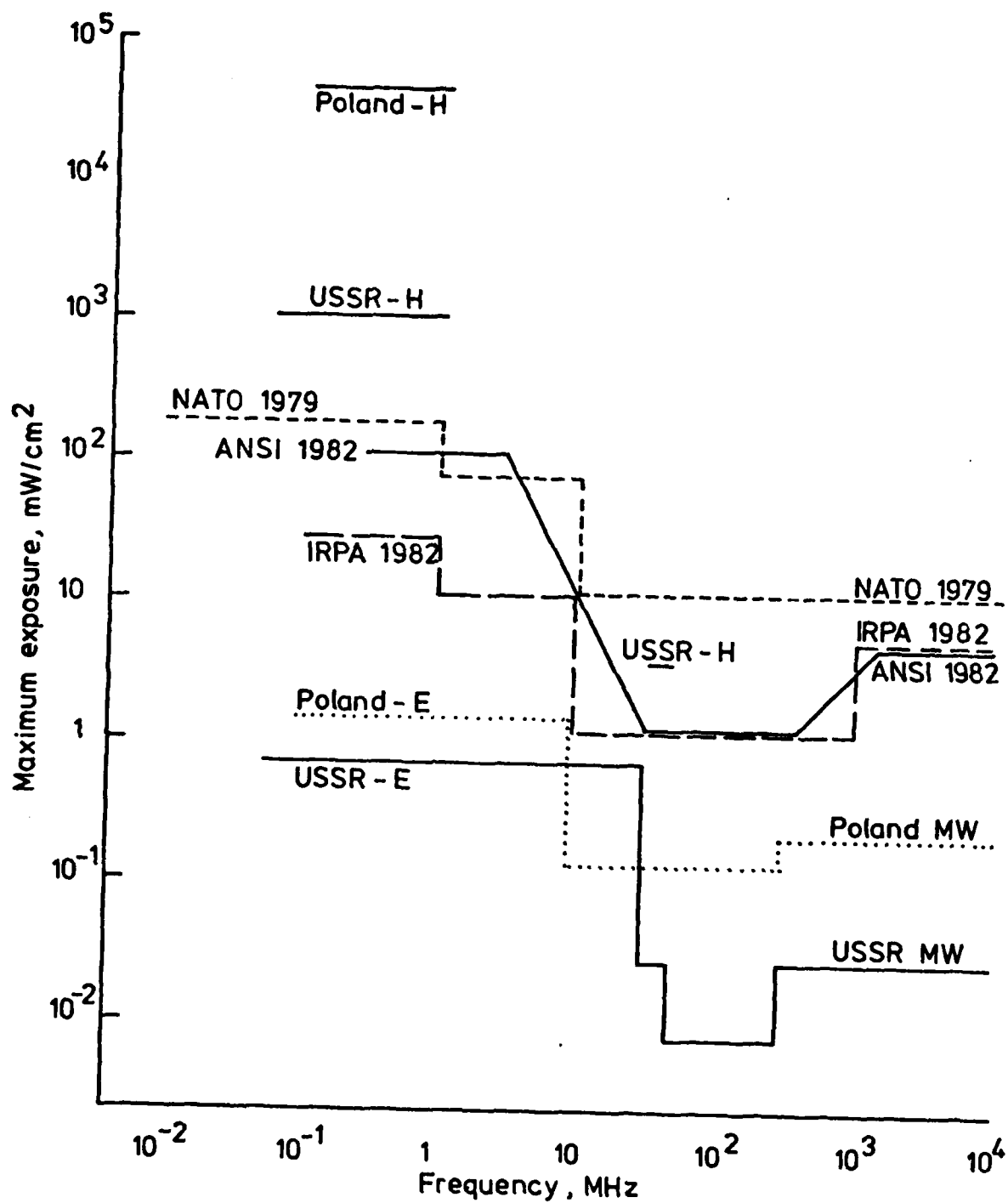


Figure 3 'Equivalent' plane wave power densities for 8 h exposure

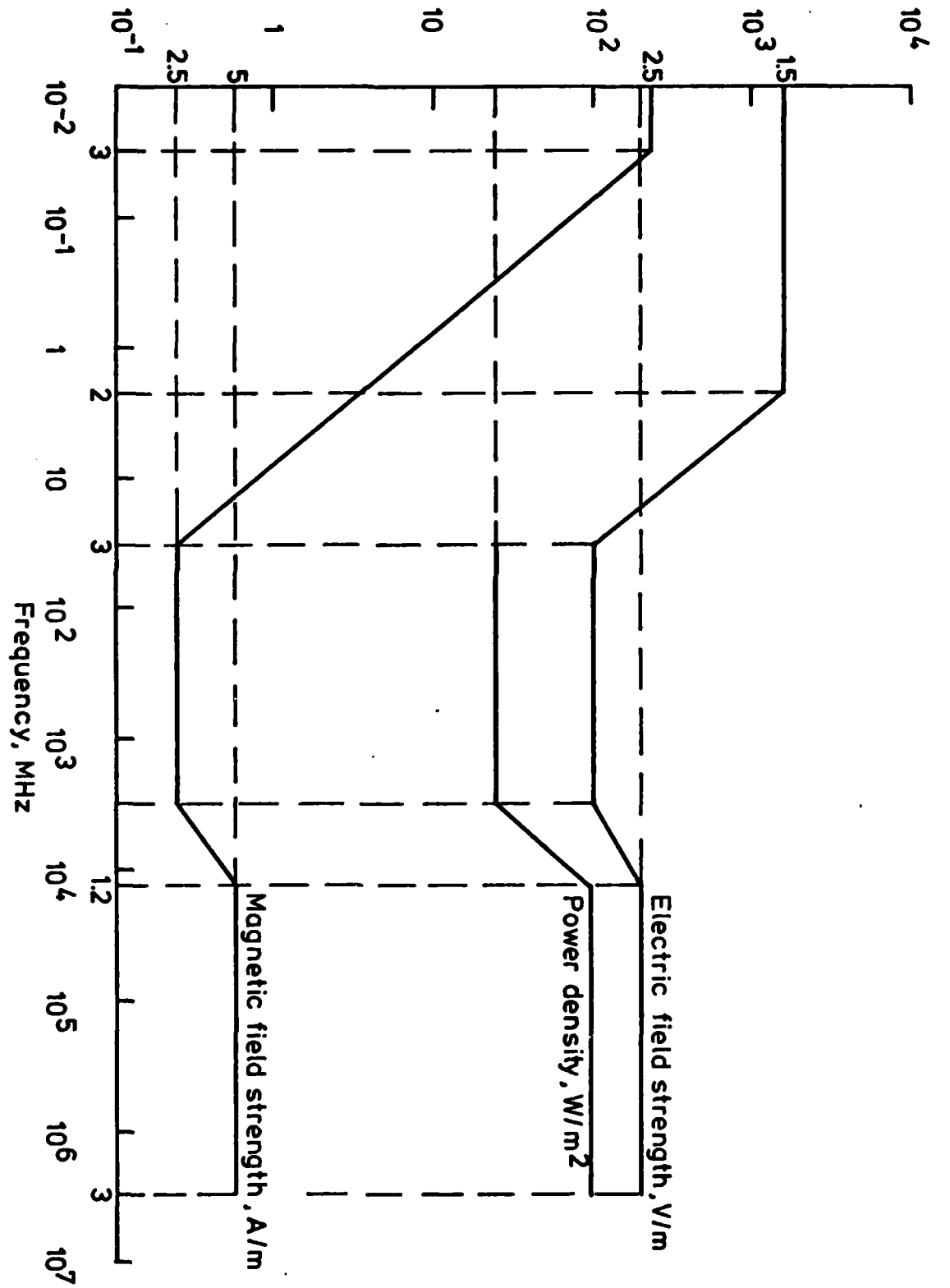


Figure 4 A proposed Federal Republic of Germany standard ~ 1979

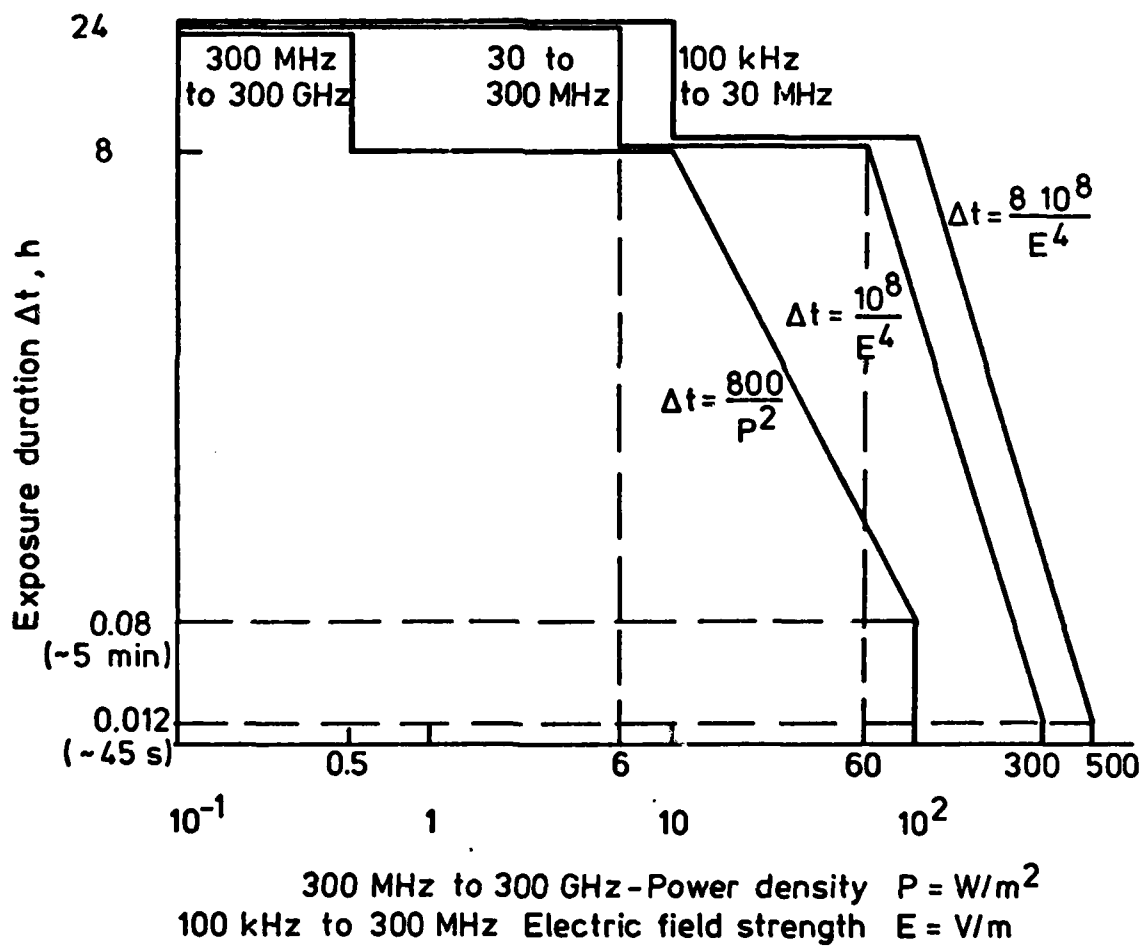


Figure 5 A proposed Italian standard ~ 1979

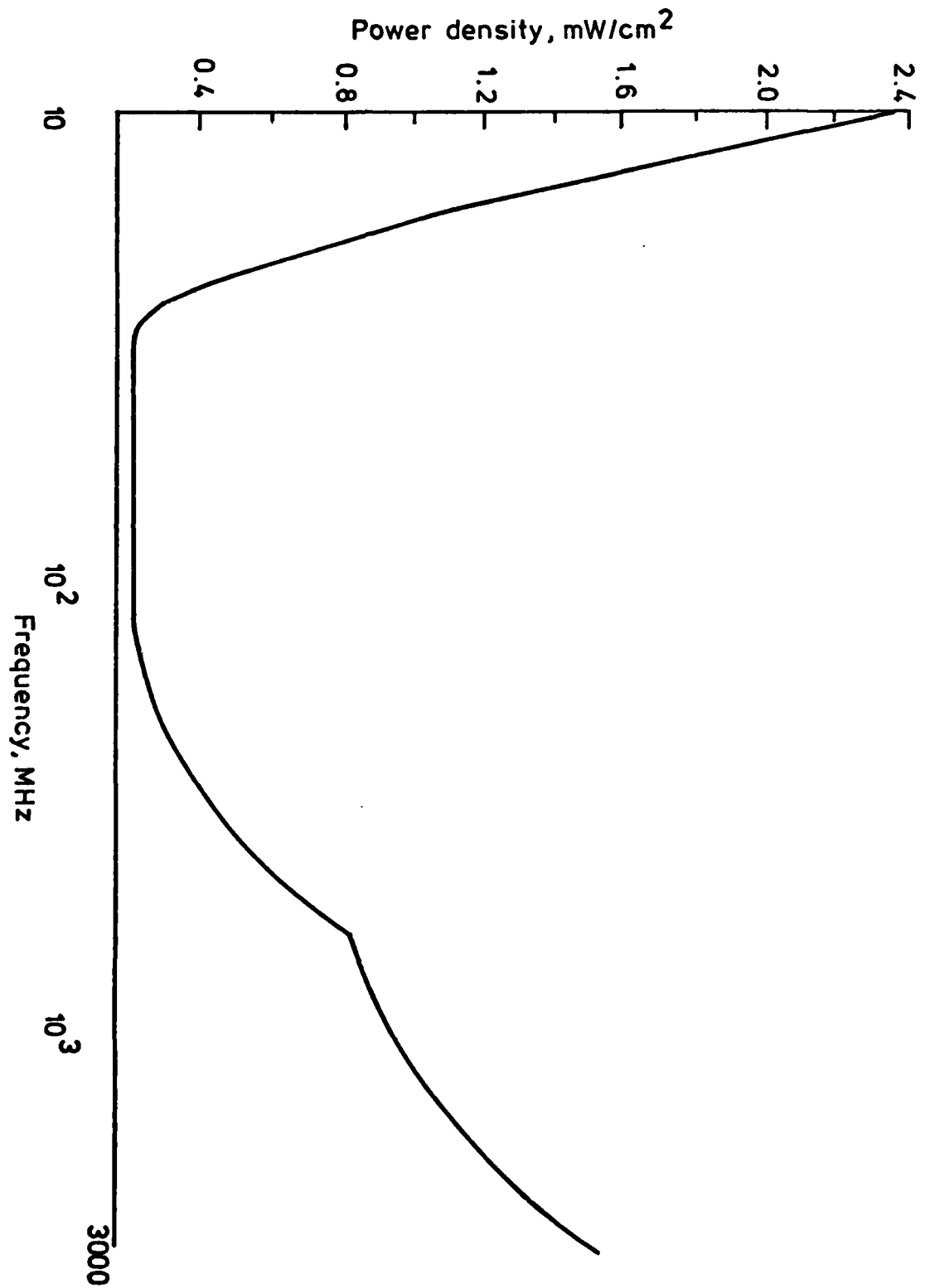


Figure 6 A proposed Australian standard ~ 1979

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RESEARCH IN BELGIUM

GENT

Laboratorium voor Elektromagnetisme en Acustica  
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Professor J. Van Bladel

This laboratory has made important contributions in the research area concerned with the interaction of acoustic waves and electromagnetic waves with various media. Very recently attention has been turned to the particular problems posed by biological media and in the course of this research tissue-equivalent materials have been developed by simulating the known dielectric properties of biological material.

RESEARCH IN FRANCE

## FONTENAY-AUX-ROSES

Institut de Protection et de Sûreté Nucléaire  
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### Dr. H. Francois

Dr. Francois is concerned with using thermolumiscent techniques for monitoring microwave radiation. His laboratory already has considerable experience in the use of these methods for measuring doses of ionising radiation.

Lithium or calcium sulphate is irradiated first with high doses of ionising radiation and this is followed by exposure to microwaves. The decrease in thermoluminescence is measured and attempts are being made to correlate this with the microwave power density.

At present the project is incomplete but it is hoped to publish the results during 1983.

## LILLE

Centre Hyperfréquences et Semiconducteurs  
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Professor Y. Leroy

The work of this laboratory is concerned with the development of non-invasive methods for measuring temperature in tissue. Two main approaches have been considered: contact radiometer probes, operating between 1 - 10 GHz which touch the skin and remote sensing devices using focused antennae which work in the millimeter range. More recently the technique of correlation microwave thermography has been developed. This is based on a coherent detection of noise and is able to improve the localization of thermal gradients in tissues.

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Leroy, Y.

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12th European Microwave Conference, Helsinki (1982)

## LYONS

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### Dr. A. Dittmar

Dr. Dittmar has developed a coaxial surface type applicator for 2450 MHz microwave hyperthermia. The end of a coaxial line is enlarged so as to give a 7 cm diameter "door knob shaped" applicator. The device is liquid cooled which enables the surface temperature of the patient to be controlled. Temperature is measured with a copper-constantan thermocouple. The applicator is being used, at present, in conjunction with Prof. Leroy of the Universite des Sciences et Technique de Lille, 59655 cedex Villeneuve d'Asq, France, to provide deep and localised heating in phantom models.

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Deep and localised hyperthermia with a new microwave surface applicator.  
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## PARIS

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Dr. A.J. Berteaud, Dr. D. Ayerbeck and Dr. M. Dardalhon

Dr. Berteaud and his colleagues are interested in the action of millimeter waves at 70 to 75 GHz and power levels of 5 to 100 mW/cm<sup>2</sup> on bacterial growth. They have also studied the genetic effects of microwaves at 9.4, 17 and 70 to 75 GHz at power levels up to 60 mW/cm<sup>2</sup> in procaryotic and eucaryotic cell systems. However no significant effects on cell survival i.e. colony forming ability and on mutation induction were observed; it was concluded that under the conditions used microwaves do not induce alterations in DNA which are subject to known DNA repair processes in procaryotic and eucaryotic cell systems.

In order to find out whether other cellular targets than DNA, for example, the cytoplasm or membranes are involved, the effects of microwaves on the growth of Escherichia coli were studied at 17 GHz, 50 mW/cm<sup>2</sup> in conjunction with X-rays and UV irradiation. The survival of wild type and repair deficient mutants of E-coli as well as the induction of mitotic intergenic recombination in the yeast strain D<sub>5</sub> was determined. The results suggest that at 17 GHz and 50 mW microwaves exert a small but significant effect on the biological endpoint studied.

The effects of 17 GHz microwaves on the multicellular organism Drosophila melanogaster were investigated. The results on the induction of lethal and mutagenic effects in the Drosophila melanogaster were consistent with the hypothesis that microwaves do not induce irreversible changes in cellular DNA.

Investigations of the thermal action of 2450 MHz microwaves on the yeast *Saccharomyces cerevisiae* have been made and the effects compared with those arising from water bath hyperthermia. However at specific absorption rates between 20 and 100 W/kg no evidence was obtained for specific effects induced by the microwaves.

Studies have also been performed at 434 MHz on *Saccharomyces cerevisiae* and it was also concluded that the thermal action of microwaves is not significantly different from that of classical heating.

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## TOULON

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### Dr. B. Seryantie

Dr. Seryantie and his colleagues are interested in the effects of low level microwave radiation on rats and mice. Animals are exposed at power levels of  $5 \text{ mW/cm}^2$  or less and the effects on behaviour and also possible differences in the action of drugs observed. Pulsed radiation at frequencies of 2.45 GHz, 3 GHz and 9 GHz is utilised and the exposure time varied from a few minutes to several days.

Effects on behaviour as judged by changes in EEG patterns were observed. Regarding drug action it was noticed that a larger quantity of a given drug had to be injected to produce a given level of paralysis for irradiated animals than for controls.

Observations have also been made on the possible effects of microwaves on humans and cases of damage to health have been reported consequent upon exposure at levels outside the recognised safety standards.

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VILLEURBANNE

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Dr. R. Santini

Dr. Santini is interested in the biological effects of both high frequency microwave fields and also magnetic fields. The purpose of his work is to study the nature of possible hazards and to investigate methods of preventing such hazards.

At present Dr. Santini is investigating the effects of non-ionising radiation on tumour development in animals and in particular melanoma B16 of black mice. He is also interested in the effects of non-ionising radiation on both bone ossification and bone fracture and also the effects of such radiation on digestive tract physiology. In particular a power density of 3 to 4 mW/cm<sup>2</sup> of 2.45 GHz radiation was applied to rats for periods of 4 to 8 hours. Although no effect was found after 4 hours it was noticed that after 8 hours there was an acceleration of the digestive transit and this was still observed after 24 hours. In all these experiments the rectal temperature of the irradiated animal did not differ from the control.

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RESEARCH IN FEDERAL REPUBLIC OF GERMANY

COLOGNE

Physikalisches Institut der Universität zu Köln  
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Prof. G. Nimtz

Professor Nimtz is working with the department of biology at the University of Köln to study the interaction of microwaves on the drosophila melanogaster (fruit fly). They are interested in low level intensities at frequencies between 1 and 40 GHz. The main interests are:

- a) the influence of irradiation on fertility up to the third generation,
- b) chromosome damage.

So far the work has only been in progress for 18 months but it is hoped that a report will soon be presented.

## MUNICH

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Dr. W. Gründler

The work described has been performed in conjunction with Dr. F. Keilmann of the Max Planck Institute, Stuttgart. It has been suggested that low level microwave radiation may have significant biological effects at specific frequencies due to the induction of coherent processes. In particular there is theoretical support for this from Fröhlich (1968, 1980) as well as experimental evidence from Eastern European countries (Devyatkov, 1974). However until recently there has been very little solid experimental evidence from Western scientists and the present work is an attempt to correct this omission. In particular the growth rate of the yeast *saccharomyces cerevisiae* has been studied when subjected to low level microwaves of frequency around 41.8 GHz. The experimental apparatus consisted of a well built and carefully controlled microwave exposure system. The yeast cells were subjected to power levels ranging from less than 1 mW/cm<sup>2</sup> to a few mW/cm<sup>2</sup>. The concentration of the yeast cells was measured by means of light scattering techniques. Careful studies were performed from 41.64 to 41.79 GHz and it was found that at certain frequencies the growth rate of the cells is unchanged whilst at other frequencies there could be an increase of up to 12% or a decrease of up to 29%. The resonances observed appeared to have line widths of only about 10 MHz.

Recently the experimental system has been further refined and the experiments repeated between 41640 MHz and 41835 MHz. These experiments have confirmed the earlier results and the authors conclude  
(a) there are changes in yeast growth rate, caused by low intensity microwave radiation

- (b) the effects depend on frequency and show a strong resonance like behaviour
- (c) the effects are not correlated with the power levels used
- (d) the effects cannot be explained in terms of simple thermal response.

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## STUTTGART

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Professor L. Genzel, Drs F. Kremer and F. Keilmann

The work on the effect of microwaves on yeast cells is described in the section devoted to Dr. Gründler.

Recently work has been carried out on the effects of microwaves on the puffing rate of giant chromosomes in salivary glands of *acricotopus lucidus*. It was shown that this rate was reduced by low level microwaves in the frequency range  $6.41 \times 10^{10}$  Hz -  $6.91 \times 10^{10}$  Hz as the power deposition was less than 3  $\mu$ W. It was concluded that this effect is non-thermal in origin.

Studies were also made of the dielectric behaviour of haemoglobin in the frequency region  $10$  GHz -  $10^4$  GHz. Three distinct relaxation processes on a picosecond timescale were identified and attributed to asymmetric double cell potentials.

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STUTTGART

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Professor F. Kaiser

Professor Kaiser is interested in the theoretical aspects of the interactions of radiowaves and microwaves with biological systems. At present the work is mainly concerned with coherent oscillations and their external perturbations by electromagnetic fields.

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RESEARCH IN ITALY

BOLOGNA

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Dr. G. Sinigaglia

Dr. Sinigaglia is studying the interaction of radiowaves with biological material. The objectives are to measure the electric and magnetic components of any fields in the frequency range of 4 to 40 MHz, which are emitted from equipment used to dry plywood or weld plastic. There is also interest in using microwave radiometry for the diagnosis of cancer and to monitor induced hyperthermia.

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## FLORENCE

Istituto di Ricerca sulle onde elettromagnetiche (IROE)  
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### Professor L. Millanta

There is much interest concerning the protection of human health against RF and microwave exposure. In particular measurement techniques for electromagnetic fields have been developed and a RF hazard monitor has been patented.

At present an Italian law has been drafted to consider methods, such as shielding and grounding, to reduce stray emission and Professor Millanta is advising on this.

There is much interest on the biological effects of microwaves with particular reference to enzymatic activity; both microwave and optical apparatus is used for activity measurements during irradiation. Work is in progress, using microwave heating, to determine kinetic parameters and thermodynamic functions of chemical reactions. Microwave heating is also being used to thaw substances of medical interest such as blood, plasma, haemodiagnostic sera and organs; this work is in collaboration with the Haemophilia Centre of the Hospital S. Maria Nuova and the urological clinic of the University of Florence.

Work is being done on RF and microwave induced hyperthermia in collaboration with the 2nd surgical clinic of the University of Florence. The main interest concerns the power and temperature distributions from various applicators. Temperatures are measured using both surface and invasive probes on phantoms which are optically transparent for liquid crystal display. Experiments have also been performed on animals to

consider factors such as power dissipation and thermal damage limits.

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## GENOVA

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### Professor A. Chiabrera

Professor Chiabrera is interested in the interactions between electromagnetic fields and cells over the frequency range of 0 to 100 GHz although at present most effort is being directed towards the lower end of the spectrum.

The main projects involve in vitro studies into the effects of electromagnetic exposure and investigation of chemical changes in the micro-environment on various cell lines such as frog erythrocytes and human lymphocytes, and the electrochemical control of cell reactivation or cell proliferation. There are also in vivo studies of the effects of electromagnetic exposure on bone fractures.

Work is in progress on the modelling of cellular bioelectrochemical processes and the computer simulation of the possible biological effects caused by electromagnetic exposure. Various exposure systems have been designed for laboratory and clinical applications.

The laboratory has pioneered the quantitative assessment of the biological effects of electromagnetic exposure at the cellular or molecular level by means of automated cytometry. In particular the high resolution analysis of cell images obtained by absorption fluorescence and phase contrast microscopy, laser flow microfluorometry and cell sorting.

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GENOVA

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Professor S. Ridella

Apparatus has been set up which uses the HP8542A network analyser and HP4191 impedance analyser to measure the complex permittivity of liquids between 50 and 2000 MHz. The experimental cell consists of an open-ended coaxial line. The reflection coefficient of its contents are measured which after suitable calculation enables the complex permittivity of a liquid to be calculated. The technique requires a sample of only 0.5 ml volume and 40 frequency points can be obtained in about 3 mins. The absolute accuracy of the system is in the order of a few percent with a repeatability of 1 to 2% in both the real and imaginary parts of the complex permittivity.

At present the apparatus is being used to measure the human blood sera of normal and cancer patients in order to look for differences between them.

At Genova work is also in progress to study, by means of suitable numerical models, the effect of EM fields on biological systems such as nuclei, membranes and whole cells. The frequency range of interest is DC to 1 GHz; the Maxwell-Wagner equation being used to consider the effect of the boundaries of the various dielectric regions. The above model is linear, however studies have also been made on the non linear behaviour of cell membranes.

The above calculations, which are done with the aid of a computer,

enable the field inside a biological system to be estimated as a function of frequency. The data obtained suggest the possibility of frequency "windows" which could be of importance regarding microwave hazards.

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NAPLES

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Professor G. Franceschetti

The bioelectromagnetics research at the above applied electromagnetics laboratory started some years ago with a research programme on the effects of EM fields on larvae and pupae of *Tenebrio molitor* coleopteron, this work being in collaboration with the Institute of Agricultural Entomology. Since then much work has been done studying the teratogenic power of microwaves by means of a systematic study of morphological anomalies induced by the electromagnetic exposure of insect pupae. A cumulative effect was found at low (non-thermal) power levels and in particular upper and lower threshold power levels were found. At present a study is in progress to investigate pulsed verses CW radiation teratogenic effects, however tentative conclusions suggest that at the same average power levels it is CW rather than pulsed fields which have the greater biological effect.

Work has also been done on exposure systems and dosimetric techniques. Mode-stirred enclosures have been developed and their performance evaluated. Using such cavities it has been possible to obtain a direct non-calorimetric evaluation of the power absorbed by exposed samples.

At present other entomological experiments are in progress, the aim being to gain knowledge regarding the use of microwaves for pest control in stored grain and other foods.

There is also interest concerning electromagnetic interaction with

biological effects at a fundamental level. A project has been initiated, in conjunction with the General Pathology Institute on the effects of EM fields on cell structure. In particular growth rates and specialised cellular functions will be investigated with the cultures are exposed to both UV and microwave fields at various frequencies and power levels.

Another line of research concerns non-linear electromagnetics and in particular the non-linear interaction of an electromagnetic field with living tissue at the cellular level. Recently calculations have been performed concerning the non-linear response of cell membranes to applied EM fields. These calculations suggest that the resting potential of a cell can be modified by an applied EM field of strength in the order of 100 V/m at frequencies around 80 MHz. Some preliminary experiments have been made in conjunction with the department of physiology.

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PALERMO

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Professor C. Tamburello

Professor Tamburello is investigating the interaction between non-ionizing radiation and biological systems and is particularly interested in non-thermal effects at the cellular level. Two experimental systems exist between 60 and 90 GHz for measuring the complex permittivity of cell sediments and to perform experiments on cells exposed to microwave radiation. This project is in collaboration with the Istituto di Igiene, also of Palermo University, where the necessary biological samples are prepared and the effects on irradiated cells are studied.

Professor Tamburello and his research group have been appointed by the Ministero della Sanità and the Italian National Research Council (CNR) to investigate the effects of non-ionizing radiation on human beings and to advise concerning safety standards.

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Radio Sci. 17, n. 2 (1982)

ROME

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Professor P. Bernardi

For several years the work in Professor Bernardi's laboratory has been concerned with dosimetric problems concerning the distribution of the power absorbed inside various models. In particular they have considered both near and far field conditions and also the influence of nearby objects on the distribution of absorbed power.

At present as well as continuing the above work the laboratory is studying the energy absorption in subjects which have been exposed to transient electromagnetic fields, in particular the impulsive type such as nuclear power pulses. Work is also being done in this direction at the cellular level to investigate such factors as membrane potential and ionic currents produced by the interaction.

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RESEARCH IN IRELAND (REPUBLIC OF IRELAND)

GALWAY

Department of Microbiology  
University College of Galway  
Galway  
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Professor J.A. Houghton

Professor Houghton is studying the effects of a range of physical and chemical agents, including radio and microwaves on the chromosomes of man and in particular the effects of these agents on the induction of chromosome aberration. At present Professor Houghton is working on a method for the direct visualization of the chromosomes of human gametes involving the technique of interspecific in-vitro fertilization. It is believed that if this technique can be made reliable, then it will allow for the assessment of the effects of agents such as radiowaves and microwaves on the induction of chromosome abnormality during human gametogenesis and the conception of chromosomally abnormal fetuses.

RESEARCH IN SCANDINAVIA

## GÖTEBORG

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Dr. H-A. Hansson

Dr. Hansson is interested in any possible effects of microwaves on the nervous system and the retina. It has been found that 3.1 GHz microwaves at  $55 \text{ mW/cm}^2$  induce alterations in the retina of rabbits after a 1 hr exposure, this work being done in conjunction with Dr. L-E. Paulsson. The work has been extended to rabbit brains, the exposure being 1 hour per day for 3 days. Differences were observed, in for example the cerebellum, 7 months after exposure. Dr. Hansson suggests that there are also differences both in nerve cells and glial cells and that there is an alteration in the distribution of various acidic proteins. In a collaborative project with the Department of Neurology of the Sahlgren Hospital cerebrospinal fluid has been examined from patients which have been occupationally exposed for long time periods to microwaves and in a few cases a significantly altered distribution of acidic proteins have been found. However at this stage it would not be possible to conclude that a relation has been shown to exist between the neuropsychiatric symptoms of the patients and the occurrence of pathological proteins in their cerebrospinal fluid

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Brain Res. 216, 187-191 (1981)

## GÖTEBORG

School of Electrical Engineering  
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### Dr. Y. Hamnerius

Dr. Hamnerius is investigating possible non-thermal genetic hazards due to microwave irradiation. Bacteria and embryos of *Drosophila melanogaster* have been exposed to electromagnetic fields in the RF and microwave regions. Control experiments were performed in which the temperature of both the exposed and non-exposed samples was kept constant during irradiation. The possibility of increased mutation frequencies was looked for but none were found in any of the test systems after exposure to the fields. However a small increase in the survival was found in the bacteria tests. Although this increase was only 6% it was considered to be significant.

Pulsed microwave radiation at a frequency of 3.1 GHz and a power density of  $55 \text{ mW/cm}^2$  was applied to the retina of rabbits. The retina were then examined by electron microscopy and changes were found in the retinal neurons.

The effect of 3.1 GHz pulsed microwave radiation on rabbit brain microtubules and axonal transport of proteins in the rabbit vagus. nerve has also been investigated. However no significant differences from the controls were found.

The permittivity of lamellar lipid water mixtures has been investigated at 2.9 GHz using a resonance technique. The results suggested that the permittivity of the water in these thin layers is the same as the permittivity of ordinary water.

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Research laboratory of electronics, Chalmers University of Technology,  
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on *Salmonella typhimurium* and *Drosophila melanogaster*.  
Submitted for publication to *Bioelectromagnetics*.

For other publications of Dr. Hamnerius please see the references of  
Dr. L-E. Paulsson (Stockholm)

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Dr. K. Jokela

The main interest concerns measuring electromagnetic fields in the frequency range of 1MHz to 10 GHz, with particular reference to radar systems and television stations. In particular a field dosimeter has been developed to measure both the E and H field component of RF and microwave radiation. In conjunction with this work calibration facilities for power density, and electric and magnetic field measurements are being developed.

## STOCKHOLM

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### Dr. L-E. Paulsson

Dr. Paulsson worked previously at the Chalmers University of Technology and his studies in collaboration with Dr. Hamnerius on rabbits have already been described in this report.

In an experiment with rats, microwave irradiation at 3 GHz and power densities of 50 and 100 mW/cm<sup>2</sup>, and galactose feeding were given either separately or in combination. It was found that rats which had been subjected to the combined treatment showed opacities visible under the slit-lamp biomicroscope. However electron microscopy revealed changes in lenses from rats subjected to microwave radiation independent of the galactose content.

Separate studies were performed on the effect of microwaves on microtubules in vitro. The binding of colchicine in brain extracts, the polymerization of microtubules and the transport of protein in nerve axons during microwave irradiation were studied, however no effects of the radiation could be seen at absorbed power densities up to 400 W/kg.

Work has also been done on model systems. In particular a model of the human head has been built and the absorption of microwave energy in the eye measured at 0.9, 2.5 and 9 GHz. The absorbed power density shows a decrease with distance from the cornea at 9 GHz. However at 2.5 and 0.9 GHz the absorbed power density pattern forms a peak within the eyeball.

It was also found that the peak values are 50 to 100% higher for protruberant eyes as opposed to the more recessed eyes.

At present Dr. Paulsson's work at the National Institute of Radiation Protection covers much of electromagnetic spectrum from kHz to the ultra-violet and also ultrasound. Indeed most of the present work is concerned with UV. At present there is interest in radiofrequency dosimetry and in particular studying the absorption and penetration of near field short wave energy in the human body. The work includes the thermographic analysis of induced temperatures in full scale models and the development of suitable materials for these models.

Projects have been funded to look for genetic effects due to microwave exposure. At present no significant effects have been found in the 50 to 100 W/kg exposure range, however a small increase in cell stimulation has been observed with both 27 and 2450 MHz.

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Mr. P. Ljung

Much of the microwave work of Mr. Ljung is in collaboration with Dr. Paulsson and is supported by the National Institute of Radiation Protection. Some of this work is of a fundamental nature concerned with measuring the permittivity of dielectric materials using a Hewlett-Packard on-line computerized system. The experimental cell is built from a precision 7 mm air line and the method is based on that described by Stuchly.

There is also interest in microwave induced hyperthermia for the treatment of cancer. Various waveguide applicators, both rectangular and cylindrical have been designed and built to operate at 2450 MHz. Experimental work has been done and some regression of breast tumours has been observed.

UMEÅ

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Dr. K. Hansson Mild

Some work has recently been started to investigate the effects of RF exposure on CHO cells. The cells will be exposed to low level 2, MHz fields and the effect of the exposure will be measured on cell parameters such as cell doubling time and cell volume; also NMR  $T_1$  and  $T_2$  relaxation times will be measured.

The effects of pulse discharge on the survival and chromosomal damage in human lymphocytes are being studied. It has been found that when a short electric pulse, in the order of 3 kV/cm and duration 1  $\mu$ s applied to a cell suspension, the cell membrane will be destroyed in some cells and in others chromosomal aberrations are seen. At present various parameters are being studied in order to investigate the above effects.

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RESEARCH IN UNITED KINGDOM

## BANGOR

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### Dr. R. Pethig

Dr. Pethig has various experimental techniques for measuring the dielectric and electronic properties of solid materials over the frequency range of  $10^{-6}$  Hz to  $3 \times 10^{10}$  Hz. Various enzymes and proteins have been investigated and a collaborative project has been established with the Xienta Institute for Skin Research (U.S.A.) to study the dielectric properties of the skin.

There is interest in the dielectric properties of water bound to protein and enzyme molecules. Hydration sorption isotherms are determined using a sensitive quartz crystal microbalance technique and dielectric measurements are made from carefully controlled humidity conditions; these studies are relevant to the consideration of the effect of electromagnetic irradiation of living tissue. Differences have been observed in the dielectric properties of normal and cancerous tissue and these are believed to be related to differences in the states of bound water.

There is also work in progress to use radio frequency hyperthermia for the treatment of cancer. Thermographic and computer assisted studies are used to investigate the absorbed power density distributions within the human body resulting from the application of R.F. electrodes of various designs. This work has assisted in the development of thermo-therapy equipment, constructed by Industrial Development Bangor (U.C.N.W.) Ltd and is undergoing clinical trials at present.

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A REVIEW OF THE CURRENT STATE OF EUROPEAN RESEARCH AND  
KNOWLEDGE CONCERNING (U) QUEEN ELIZABETH COLL LONDON  
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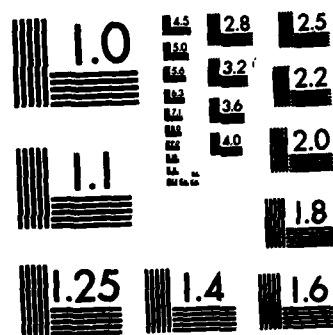
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MICROCOPY RESOLUTION TEST CHART  
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DIDCOT

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Dr. H. Smith, Dr. R.D. Saunders

There is a study in progress of the effect of electric fields on the central nervous system of the rat. Particular interest is shown in the low frequency low amplitude fields used in the studies of calcium efflux in the chick brain by Bawin and Adey. In future work slices of rat brain will be exposed to low frequency electric fields in an attempt to replicate the early studies of Bawin and Adey.

Work is also being done on the induction of cataract by microwave radiation. Interest is primarily centered on the mechanisms of cataract formation and the possibility of cataract development from repeated sub-threshold acute exposure or from chronic exposure to occupational levels. Some of this work has been carried out in conjunction with Queen Elizabeth College, London.

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Dr. R.H.C. Bental

Dr. Bental is interested in using RF for wound healing. In particular pulsed RF at 27 MHz has been applied to both rat abdominal wounds and also human calf wounds. In these experiments it has been found that the wounds treated with RF heal significantly faster than the controls.

Recently clinical data have been gathered concerning the therapeutic effect of a small portable RF unit being used on patients with varicose ulcers and pressure sores and a positive physiological response has been obtained. Also a limited number of clinical bone non-unions have been treated with successful results.

In order to investigate such effects in more depth a new clinical biophysics unit has been set up at Edinburgh University. The initial emphasis of the laboratory and clinical studies will be concerned with the use of small RF units to treat human chronic wounds and in particular decubitus ulcers and varicose ulcers.

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Professor E.H. Grant and Dr. R.J. Sheppard

One of the major interests of the research team at Queen Elizabeth College concerns the state of water, in aqueous solutions of biological molecules and in whole tissue. In particular the electrical properties of the free and bound water in such substances are particularly relevant to the absorption of energy in the RF and microwave regions.

Apparatus exists to measure the complex permittivity, in the frequency domain, of liquids from 5 kHz to 70 GHz and tissues from 2 to 18 GHz; both liquids and tissues can be measured between 10 MHz and 10 GHz in the time domain using time domain spectroscopy (TDS).

Aqueous solutions of low-density lipoproteins (LDL) have been studied and the effect on the LDL molecule of various enzymes has been investigated. At present myoglobin and PYP solutions are being measured over a wide frequency range in order to obtain information concerning the relative proportions of free and bound water present in these systems. In another project, carried out in collaboration with Smith, Kline and French Ltd, measurements have been made of the dipole moment of drug molecules used in the treatment of peptic ulcer. Comprehensive studies are also being made of rabbit ocular tissues and mouse brain tissue. The purpose of these studies is to gain insight into the mechanism of the interaction of microwaves with biological tissue.

There is also interest in the application of microwave induced hyperthermia to the treatment of cancer. Various coaxial applicators, contained within the needle of a hypodermic syringe, have been built and tested. Temperature measuring instruments which have been devised include microthermocouples and a novel instrument in which a measured vapour pressure is correlated with temperature. The complex permittivity of various mouse tissues has been measured and compared with that of tumour tissues and significant differences have been found between 10 and 100 MHz.

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Dr. J. Hand

At the MRC Cyclotron Unit research into the interactions of radio-waves and microwaves with biological material is being carried out to develop and assess hyperthermia in the treatment of cancer patients.

Various heating methods have been developed; at 2450 MHz and 915 MHz direct contact applicators are employed to heat superficial tumours, for example recurrent breast carcinoma. Such tumours have also been treated at 27 MHz by induction heating. Intracavity microwave applicators are being developed to treat carcinoma of the uterine cervix. The development of microwave applicators with specific applications is underway in a collaborative programme with Professor R. James from the Department of Electrical and Electronic Engineering, The Royal Military College of Science, Shrivenham, U.K.

Pre-clinical work has included studies of thermal dosimetry during localised hyperthermia in pigs and the response of pig skin to combined treatments of X-rays and microwave heating.

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Dr. C. Jones, Dr. P. Carnochan

Clinically effective localised hyperthermia apparatus is being developed for operation at 27 MHz. Various applicators, both capacitive and inductive are being developed with the aid of simple phantom models and computer simulations. Since the main emphasis of the work is to develop practical clinically useful methods consideration has been given to thermal dosimetry problems associated with hyperthermia treatment, and optimisation of implanted thermocouple probes for temperature measurement.

Further work is in progress to utilise such probes to quantify the effects of tissue vasculature, in conjunction with IR thermography and external heat sources. Magnetic field studies are also being undertaken with respect to the exposure of operating personnel to potentially hazardous levels of stray fields surrounding hyperthermia equipment.

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Dr. C.W. Smith

Dr. Smith has a particular interest in ELF fields on both E-coli and yeasts. Various enzymes have been studied over parts of the E-M spectrum to investigate dielectric properties and magnetic susceptibility. There is an interest in the effect of RF on plants and measurements have been made in conjunction with Dr. F.X. Hart from Sewanee U.S.A. Work has been done on bovine eyes concerning the formation of cataracts and human patients have been studied to look for differences between normal and cancer tissue.

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